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UAV Electromagnetic Sensors for Spectrum Sensing and Propagation Environment Assessment [video]

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UAV Electromagnetic (EM) Sensors for Spectrum Sensing and Propagation Environment Assessment

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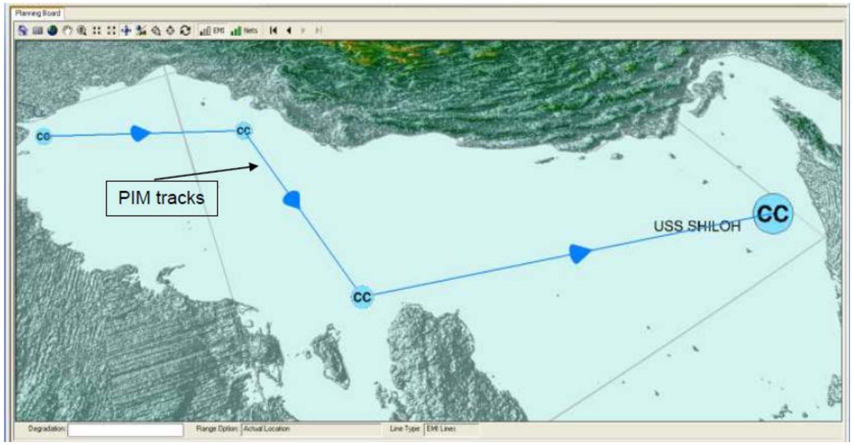
EM Propagation

- Electromagnetic (EM) radiating and sensing systems are affected by the propagation environment
  - Obstructions (buildings, terrain, etc.)
  - Material properties (ground, ice, building wall materials, etc.)
  - Meteorological phenomena (sea state, wind, rain, snow, humidity, temperature, pressure, etc.)
- Shipboard EM emitters
  - Communications and data links (terrestrial, airborne, and satellite)
  - Jammers
  - Radar
- Passive receiving systems
  - GPS
  - Intercept receivers
  - Direction finders

EM Propagation Effects

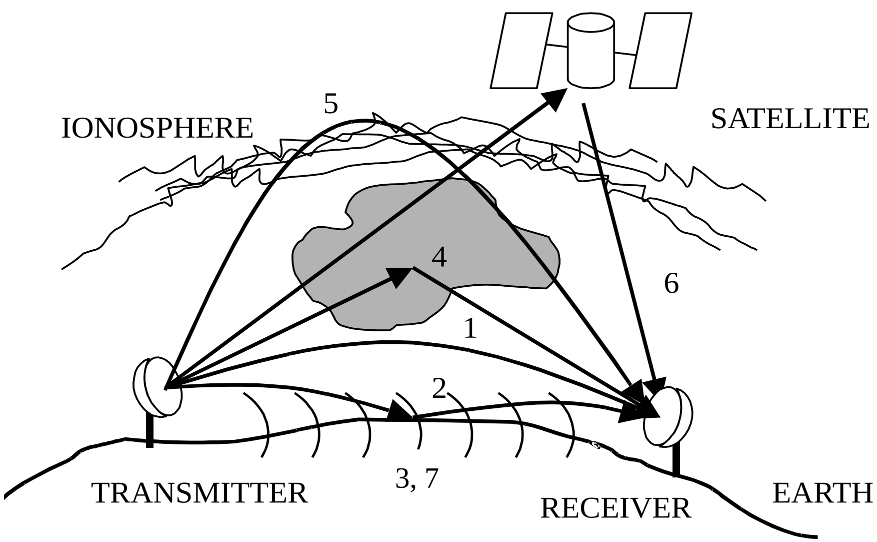
- Focus on terrestrial (near surface) emitters and receivers
- VHF and higher frequencies (30 MHz to 30 GHz)
- Impact on systems and operations
  - Reduced range, limited field of view, degraded accuracy and resolution in sensor system measurements
  - Affects probability of being intercepted by passive receivers (i.e. setting of EMCON state)
  - Control of the spectrum, spectrum management, frequency de-confliction
  - Susceptibility to jamming

AESOP planning board



Propagation Mechanisms

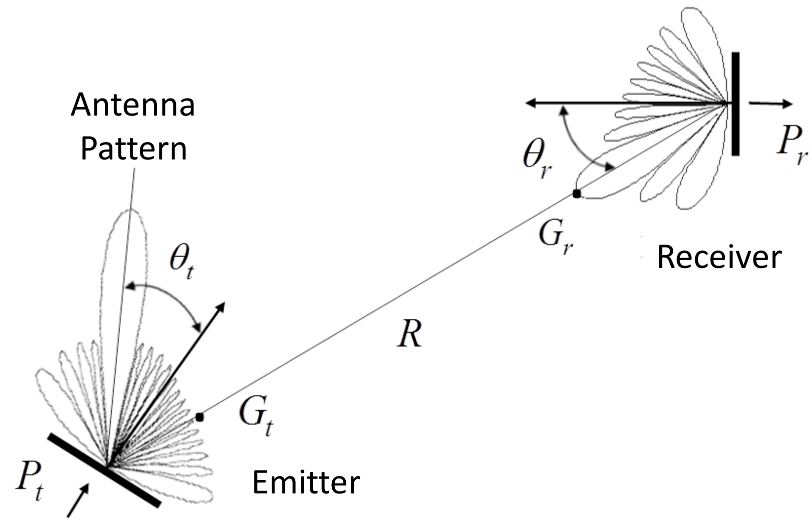
- A *propagation mechanism* is a physically distinct process by which the signal may travel from the transmitter to the receiver
- The troposphere is the lower region of the atmosphere (< 10 km)
- The ionosphere is the upper region of the atmosphere (50 km to 1000 km)
- The environmental effects on EM waves include reflection, refraction, diffraction, attenuation, scattering, and depolarization



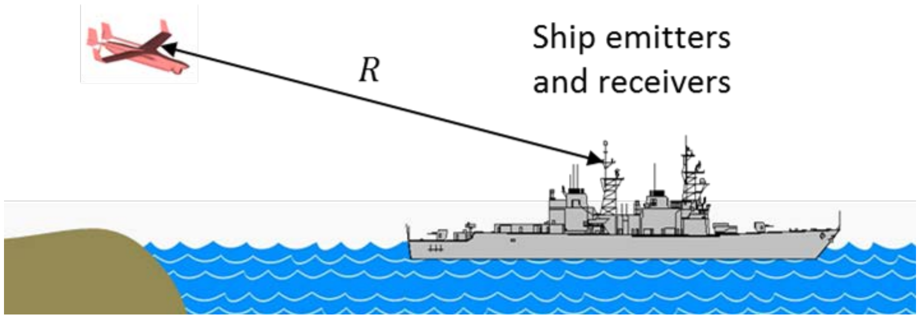
1 Direct
2 Reflected
3 Surface or ground wave
4 Troposcatter
5 Ionospheric reflection ("skywave")
6 Satellite relay
7 Anomalous (ducting)

Propagation Loss Calculation

- Governing Friis equation
- Must know or estimate all other parameters to back out propagation loss relative to free space line of sight, L_{prop}
- Measurements from ships, UAVs and ground



$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} L_{pol} L_{sys} L_{prop}$$



P_t = power into transmit antenna
P_r = power out of receive antenna
G_t = gain of transmit antenna
G_r = gain of receive antenna
L_{pol} = polarization efficiency
L_{sys} = system loss factor
L_{prop} = propagation factor relative to free space (can be > 1)

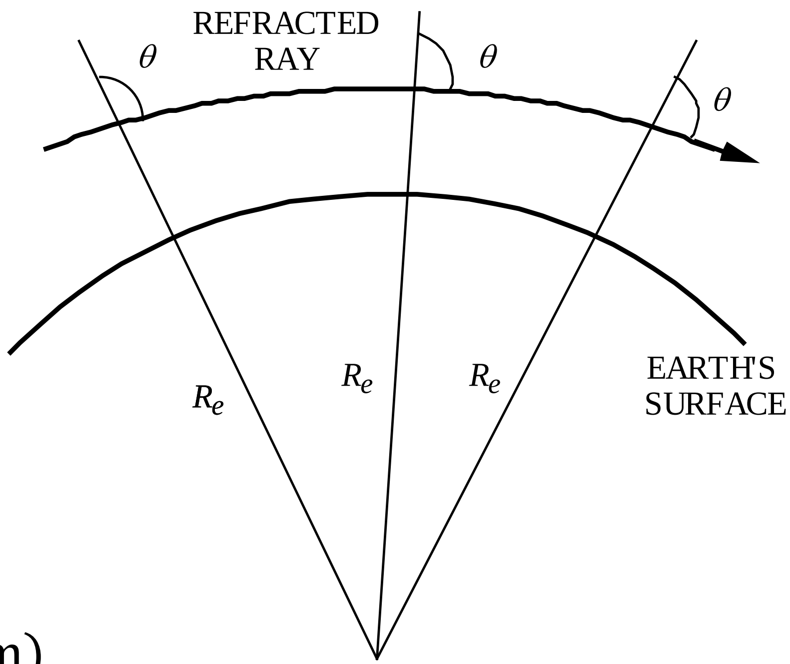
Refraction

- Near the surface the density of air decreases linearly with altitude
- Refraction is present – EM wave ray paths are not straight lines
- The ray trajectory is described by the equation: $n\, R_e \sin\theta\ = \text{constant}$
- n is the index of refraction

$$n = \frac{77.6}{T}(p + 4810\ e/T)\,10^{-6} - 1$$

where:

R_e = radius of the Earth
T = temperature (K)
p = air pressure (millibars)
e = partial pressure of water vapor (millibars)



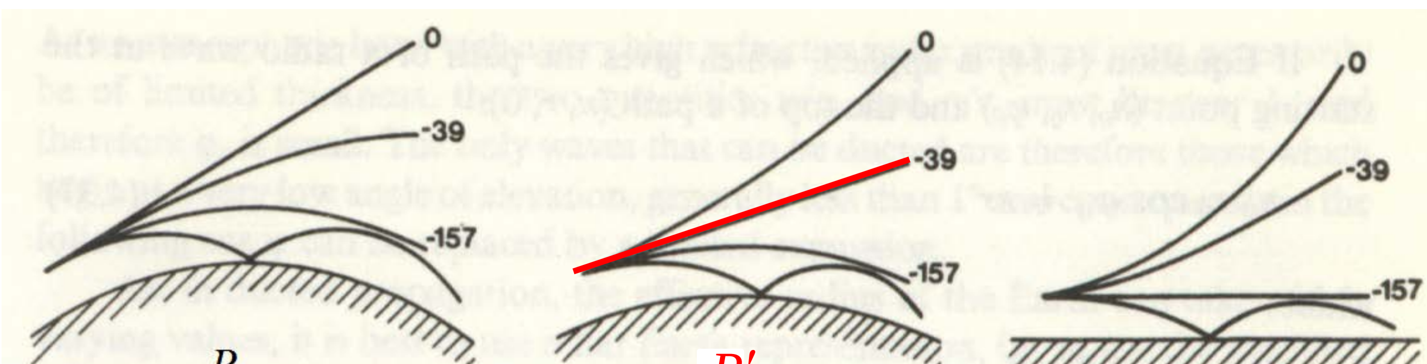
- A typical example near the surface:

$n = 1.0001$ ($n = 1.00 \ldots$ for a vacuum)

Equivalent Earth Radius

- Because variations in the index of refraction are so small, a quantity called the refractivity is used: $N(h) = [n(h) - 1]\, 10^6$
- Using an equivalent Earth radius R_e' allows straight rays to be drawn
- In the normal (standard) atmosphere the gradient of the vertical refractive index is linear with height, $dN/dh \approx -39$ N units/km or $R_e' = (4/3)R_e$
- If $dN/dh < -157$ then rays will return to the surface

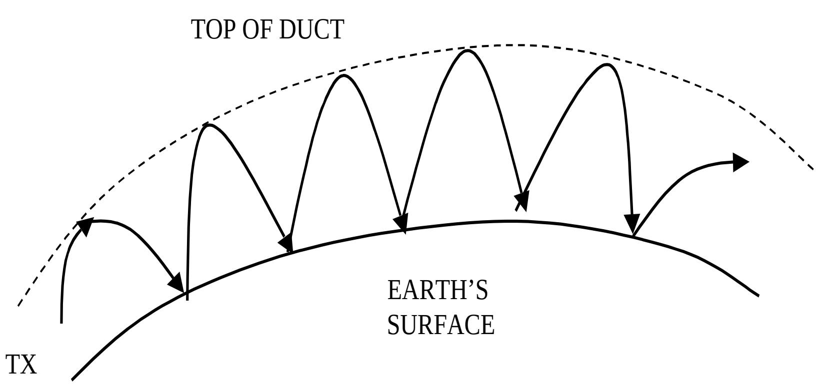
True Earth | Equivalent Earth for Standard Atmosphere | Flat Earth



R_e | R_e' | ∞

Ducting

- The formation of surface ducts is due primarily to water vapor, and therefore they tend to occur over bodies of water (but not land-locked bodies of water)
- They can occur at the surface or up to 5000 ft
- Thickness ranges from a meter to several hundred meters
- The trade wind belts have a more or less permanent duct of about 1 to 5 m thickness



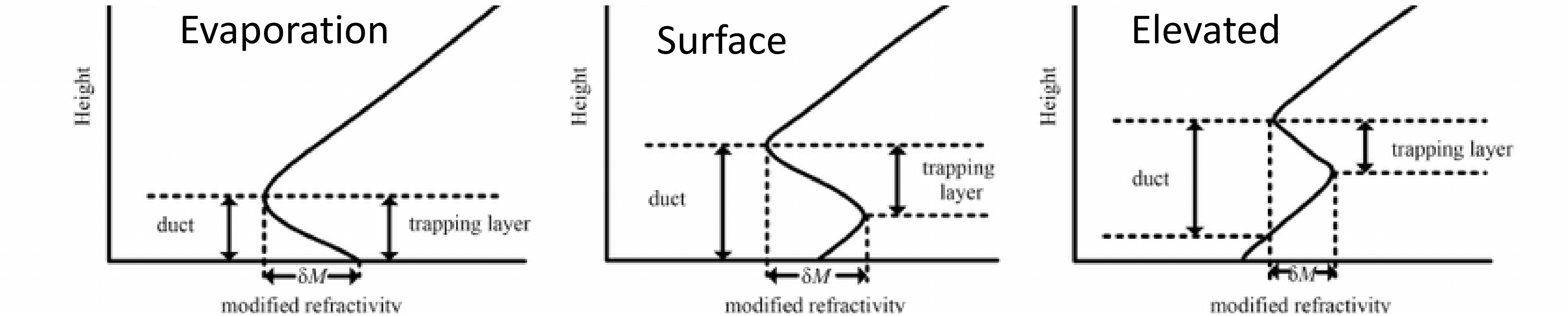
Long range propagation in a duct can be good or bad

- Efficient propagation occurs for UHF frequencies and above if both the transmitter and receiver are located in the duct
- If the transmitter and receiver are not in the duct, significant loss can occur before coupling into the duct

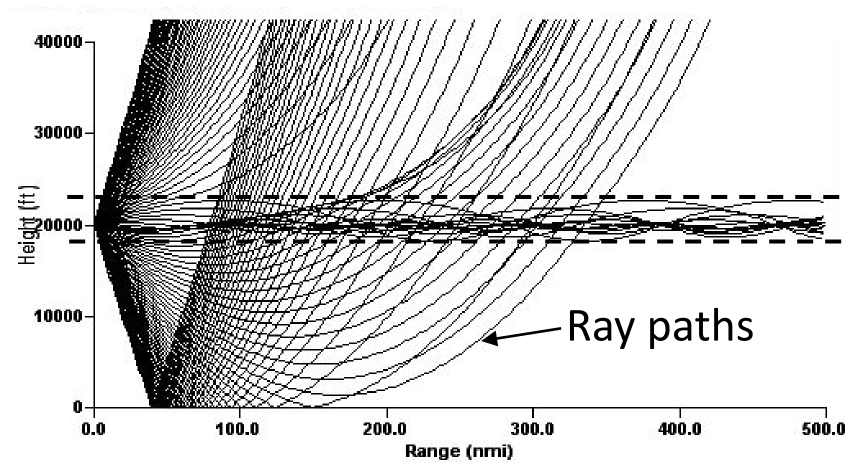
Conditions for Ducting

- Define the modified refractivity in M units per meter is

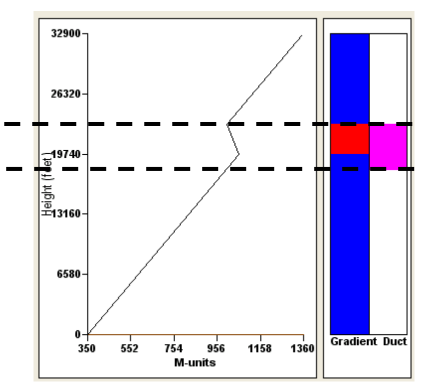
$$M(h) = N(h) + 10^6(h/R_e)$$



Elevated Duct



M profile

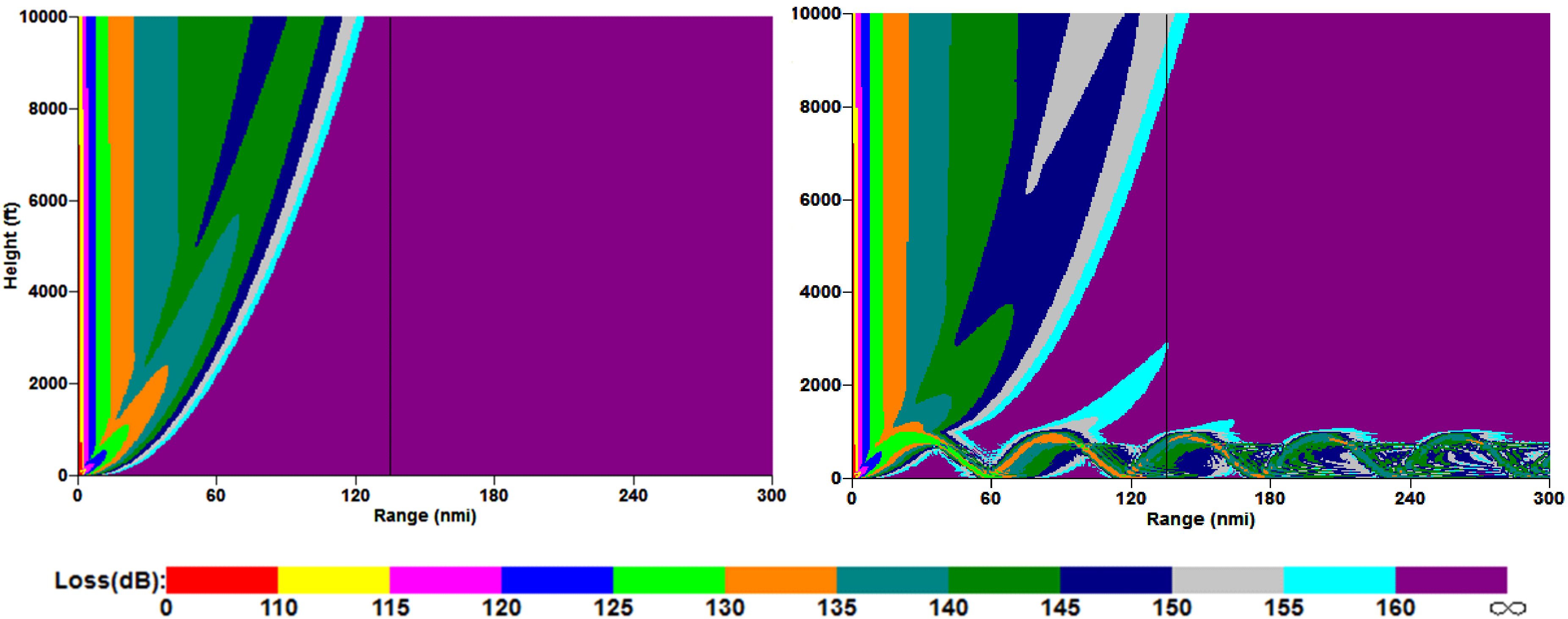


Propagation Loss

- AREPS simulation
  - Seawater, antenna height 15 ft, frequency 3 GHz
  - Contour plots of L_{prop} in decibels (dB) in flat Earth

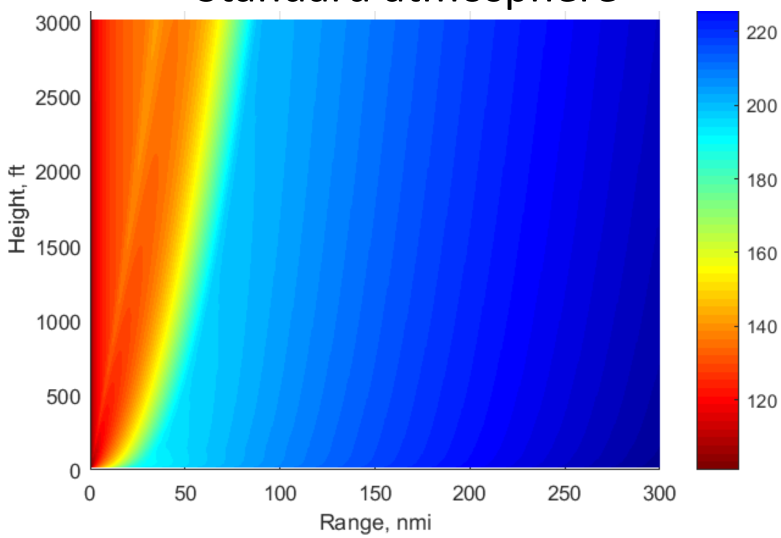
Standard Atmospheric Conditions

Anomalous Propagation

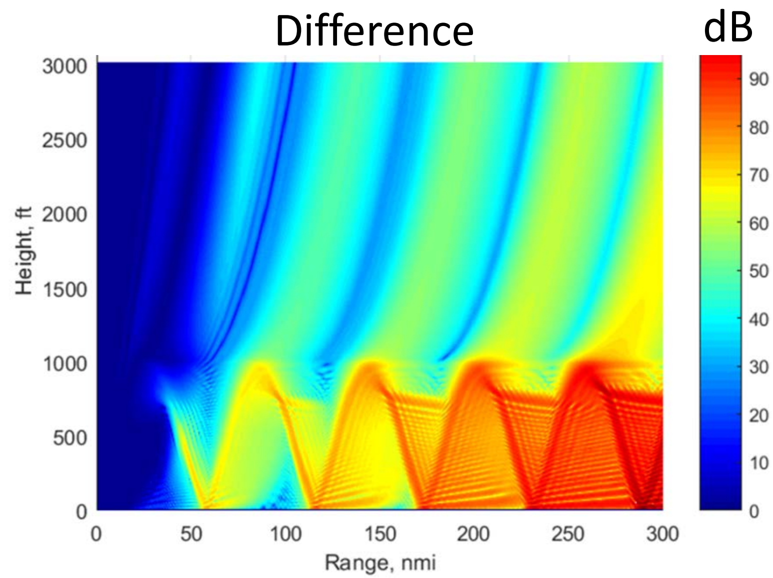


Detecting a Duct From Loss Contours

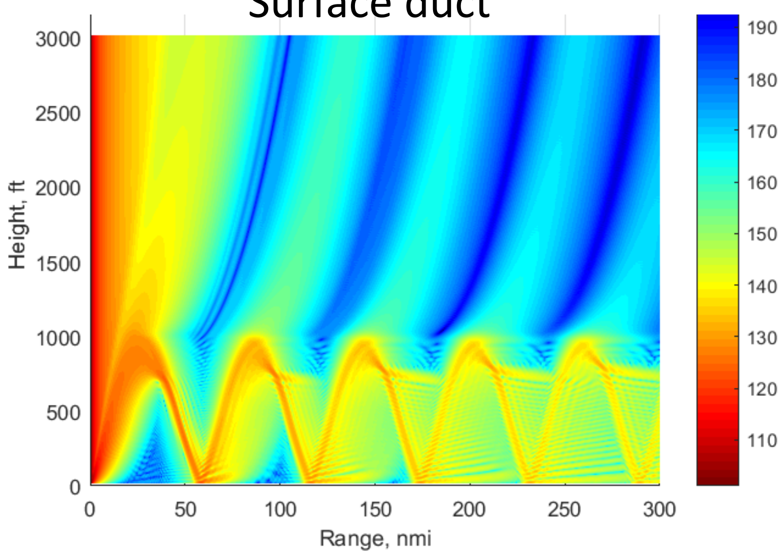
Standard atmosphere

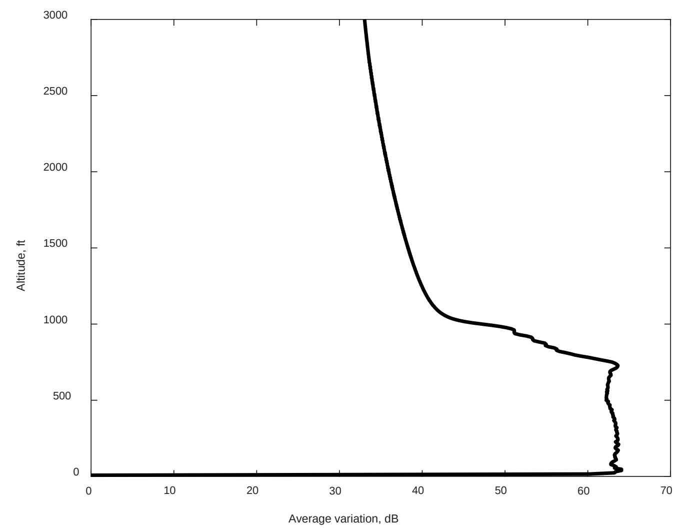


Difference



Surface duct





Sensor Data Collection

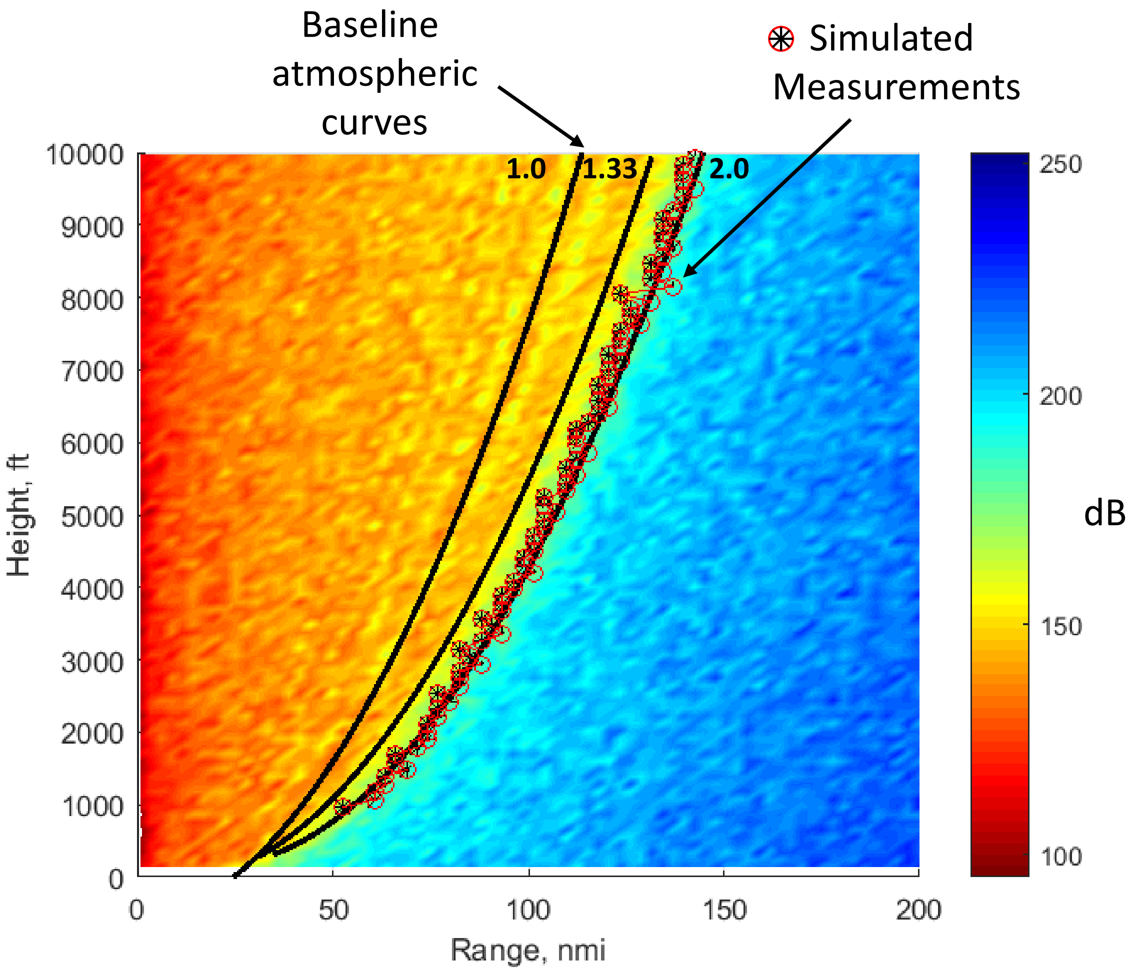
- Objective of the sensing process
  - In real time, estimate the refractivity of the propagation environment based on transmission loss between multiple transmitters and receivers
  - Determine if a duct is present and estimate its properties
- Measurement and collection procedure
  - Number of UAVs and flight patterns
  - Sampling intervals (space and time)
- Data processing
  - Compare measured data to values and trends in templates or baselines of
    - Historical data
    - Simulation data
    - Measured data

Work in progress

  - Merge with meteorological data to enhance the real-time propagation model

Estimating the Gradient From Loss

- AREPS simulation
  - Gradient 2.0
  - $R_e' = 2R_e$
- Includes errors in
  - Location
  - Measurement
- Simulated measurements are compared to ideal baseline curves



Summary

- Propose to measure signal loss between a number of sources and receivers on ships and UAVs to build a picture of the electromagnetic environment and the propagation conditions
- Distributed transmitters and receivers on UAVs can provide a more detailed EM "map" over large distances and a wide frequency band
- The EM data can be used in parallel with meteorological data to enhance the real-time propagation model
- Simulations show that useful estimates of propagation conditions can result
- Recent developments in commercially available small transmitters and receivers make of outfitting large numbers of UAVs with EM sensors feasible and affordable

Questions?